

Effect of Fire on the Herpetofauna of the Koanaka Hills, Ngamiland, Botswana

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ABSTRACT: Ngamiland is one of the most remote regions in Botswana, and its herpetofauna is largely under-surveyed. This study documents the herpetofauna of the Koanaka Hills (KH) in Ngamiland in 2009 following extensive fire destruction and compares it to the pre-fire herpetofauna collected in 2008. We also provide new records for the region for three amphibian and six reptile species, and document vouchers for two taxa that were sighted but not collected in 2008. During 2009, 14 reptile and three amphibian species were collected, bringing the total number of confirmed herpetofaunal taxa near the KH to three amphibian and 19 reptile species. For seven species this is the first published occurrence in quarter degree square 2021 Aa. Analyses measuring changes in the KH herpetofauna following the fire are inconclusive due to differences in collection effort and weather conditions. However, these data suggest that fire impact was minimal.

INTRODUCTION

The herpetofauna of Botswana is poorly studied when compared to that of adjacent South Africa, Namibia, and Zimbabwe. In 1856, Wahlberg was the first to comment on the country's herpetofauna, noting the presence of a puff adder (*Bitis arietans*) near Lake Ngami (Wahlberg 1994). However, the herpetological literature pertaining to Botswana as a whole is limited. Botswana is included in several guides and general publications about the herpetology of southern Africa (*e.g.*, FitzSimons 1943; Visser 1984; Broadley 1990; Branch 1998; Channing 2001; Alexander and Marais 2007; Du Preez and Carruthers 2009), but the only books specific to the herpetofauna of the country are Auerbach (1987) and Clauss and Clauss (2002). In addition, a relatively small number of technical publications have addressed the herpetofauna of selected regions or dealt with selected taxonomic groups (*e.g.*, FitzSimons 1935a, b; Haacke 1966; McLachlan 1981; Auerbach 1984, 1985, 1986; Butchart 2000; Bauer *et al.* 2009). The paucity of published data on the herpetofauna of Botswana makes any new contributions especially critical in gaining a better understanding the country's reptile and amphibian fauna.

In 2008, the then-recent discovery of microvertebrate fossils in a Pleistocene cave system in the Koanaka Hills of northwestern Botswana (Kennedy *et al.* 2010) in addition to the poor understanding of the region's modern fauna prompted a collecting trip to document the area's amphibians and reptiles and to create a preliminary comparative collection for the interpretation of the fossil herpetofauna (Bauer *et al.* 2009; Ferguson *et al.* 2010). Three months following the initial collecting trip in the Koanaka Hills, the region was consumed by a concentrated bush-fire (M. Gabadirwe, pers. com.). A follow-up survey of the area was undertaken 13–29 July 2009 to document potential changes in the fauna following the fire. An additional objective of the second survey was to provide

a more comprehensive assessment of the Koanaka Hills modern fauna.

MATERIALS AND METHODS

Study Site

The Koanaka Hills comprise three separate hills in Ngamiland Province in northwestern Botswana (Figure 1). Two hills, Koanaka North and Koanaka South, are separated by ca. 0.5 km. The third hill is 12 km to the west. The cave system documented to contain Pleistocene fossils is in Koanaka South (Pickford and Mein 1988; Pickford 1990; Kennedy *et al.* 2010), so in 2008 collecting efforts were focused there (Bauer *et al.* 2009). However, in 2009 we expanded the survey to also include Koanaka North. Koanaka South (20°09.45'S, 21°11.76'E) and Koanaka North (20°08.42'S, 21°12.23'E) are approximately 130 km southwest of the westernmost, main channel of the Okavango Delta and 20 km east of the Namibian border. The hills are composed primarily of dolomitic rocks and breccia infills (Cooke 1975) and, at ca. 50 m above the surrounding plains, they represent the only topographic relief for over 20 km. The next closest hills are the Gcwihaba Hills which lie ~23 km northeast of the Koanaka Hills (Figure 2). The site is within quarter degree square 2021 Aa (QDS 2021 Aa), the northwesternmost 1/16th of the degree square 20°S, 21°E. The area of a quarter degree square varies with latitude, though QDS 2021 Aa encompasses approximately 724 square kilometers. The two main Koanaka Hills (Koanaka North and Koanaka South) and the surrounding pans occupy about 5 km² in the northwestern corner of QDS 2021 Aa. See De Waal (1978) for more on the QDS system, which is commonly employed in biodiversity and distributional studies in southern Africa.

The habitat around the hills is a semi-arid, dense, shrub savanna, referred to as the Kalahari Thirstland (Pickford and Mein 1988). Annual rainfall of 400–450

mm occurs primarily during the austral summer months (Van Regenmortel 1995). Two pans (ephemeral ponds) are located approximately 200 m west of Koanaka South, although neither the frequency with which these pans contain water nor the duration for which they hold water is known. No signs of water in the pans were obvious during the months of June–August in 2007, 2008, or 2009. The pans are comprised of calcareous clays overlying calcrete and are separated from the rocky outcrops of the hills by dense scrub brush. Annual temperature variation near the Koanaka Hills varies from -8.5°C to 42.2°C (Botswana Department of Meteorological Services 2009). During the 2009 collection period daytime temperatures averaged 28°C , nighttime temperatures averaged 5°C , and light precipitation occurred for less than 10 minutes on one day. Field reconnaissances in both 2008 and 2009 took place during the winter dry season.

Data Collection

New collections were made primarily within a 5 km radius of Koanaka South and a 1 km radius of Koanaka North. However, one additional collecting day was spent at the nearby Gcwihaba Hills. All collections were made between 881 and 993 m asl. Collecting teams of two to four people concentrated on rocky outcrops of the hills and in the dry pans west of Koanaka South. Searches were made during both day and night, although rapid temperature drops after sunset precluded most nocturnal reptile activity. As a result, most specimens were caught from 9:00 h to 16:30 h.

Most specimens were collected opportunistically by hand. However, a few specimens were collected using pitfall and funnel traps. Two arrays of drift fences with pitfall traps were set near the base of Koanaka South in the scrub brush. One array was Y-shaped with a pitfall trap on the end of each arm and one in the center. Funnel traps were placed in the center of each arm on the Y-shaped array. The second line was a straight fence with three pit-fall traps. Pitfall traps within each array were placed approximately three meters apart. Each array was built with 0.5 m tall drift fence made out of black plastic sheeting and wooden stakes, and five liter buckets were used for the pitfall traps. Double-sided funnel traps were made out of fine mesh wire sheets. The arrays were checked twice a day, once just after sunrise and once just before sunset. Unless otherwise noted below, all voucher specimens were collected by hand.

Specimens were euthanized with intraperitoneal injections of sodium pentobarbitol. Samples of either liver or tail tissue were taken from each specimen for future DNA sequencing. When present, stomach contents and parasites also were collected. The first four specimens of each taxon collected were prepared as osteological specimens and associated skins were preserved in 70% ethanol. Every fifth specimen of a taxon collected was fixed in 10% formalin in the field and later transferred to 70% ethanol. All material was deposited in either the Texas Natural History Collections (TNHC) at The University of Texas at Austin, Austin, Texas, USA or the Botswana National Museum (BNM), Gaborone, Botswana. Specimens deposited at BNM are still awaiting catalog numbers so have been listed here with field numbers (KHH).

Our 2009 records presented here are supplemented by data from the 2008 collections and a small collection made by Wulf D. Haacke at the Koanaka Hills in 1965 as previously published by Bauer *et al.* (2009). Our list of vouchered species includes all species represented by specimens actually collected near the Koanaka Hills. Species not collected but expected to occur in the Koanaka Hills (based on literature and museum records) are listed in Table 1.

Specimens were collected under permits CHA 1/17/2 IX (64) and CYSC 1/17/21 (81) issued by the Botswana Ministry of Youth, Sport and Culture to P. J. Lewis and imported into the United States under permits from the U.S. Centers for Disease Control and Prevention, U.S. Fish and Wildlife Service, and U.S. Department of Agriculture APHIS Permit 105705 issued to M.L. Thies. Species identifications followed standard regional references (*e.g.*, Auerbach 1987; Branch 1998; Alexander and Marais 2007; Du Preez and Carruthers 2009). Amphibian taxonomy follows du Preez and Carruthers (2009). Reptile taxonomy follows Uetz (2012) and the primary sources cited therein,



FIGURE 1. Map of Botswana showing the position of the Koanaka Hills in Ngamiland (Bauer *et al.* 2009).

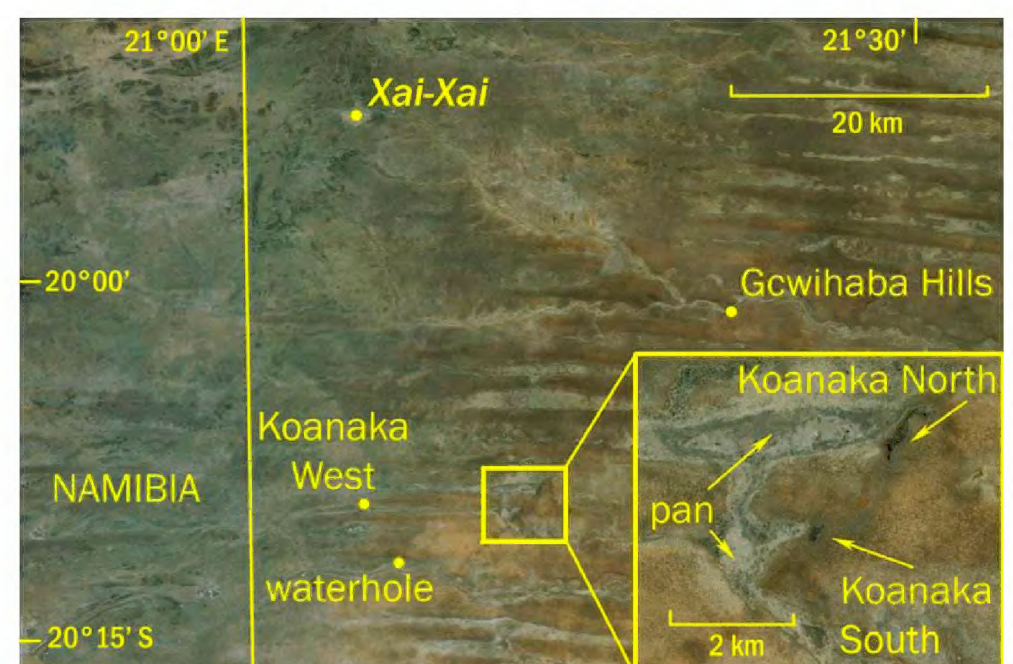


FIGURE 2. Map of a portion of northwestern Botswana showing landmarks and place names mentioned in the text. Inset shows Koanaka North and Koanaka South in greater detail (Bauer *et al.* 2009).

except for the recognition of family level taxa within the Elapoidea, for which we follow Kelly *et al.* (2008, 2009).

Data Analysis

To test whether the herpetofauna near the Koanaka Hills changed following the concentrated bush-fire in the region in late 2008, species richness, composition, and diversity were compared between the 2008 and 2009 collections. However, as described in detail in the discussion, sampling effort during the 2009 collecting season was greater than that in 2008. Therefore, these comparisons must be evaluated in this light.

Species Richness Estimation: Rarefaction curves estimate true species richness through the random resampling of the given data (Lyman 2008). To detect a change in species richness after the fire, we compared Chao 2 rarefaction curves for each year. Chao 2 is particularly useful for calculating species richness based on small sample sizes (Ugland *et al.* 2003). Chao 2 values were calculated in EstimateS and graphed in Excel. The resulting rarefaction curves were then visually analyzed for overlap. Any overlap in rarefaction curves suggests a non-significant difference in the faunas, whereas no overlap indicates a significant difference.

Species Composition: Because the goal of this study was to measure the differences between years, we calculated the Jaccard dissimilarity index ($J = C / (A + B - C)$; where: A = number of taxa in fauna A; B = number of taxa in fauna B; C = number of taxa common to both faunas). That index emphasizes differences in taxonomic composition (Lyman 2008). The Jaccard index results in a number ranging 0-1, with 1 implying that the taxon compositions are completely different and 0 implying that they are identical (Lyman 2008).

Taxonomic Diversity: For analyzing the differences in taxonomic diversity, the mean Shannon Diversity index ($S = - \sum P_i (\ln P_i)$; where: P_i = proportion (P) of taxon i in the fauna) for each year was calculated and statistically compared using a Student's t-test in the statistics program JMP. To establish the variation of the Shannon indices within years, a Shannon index was calculated for every three collecting days in EstimateS.

RESULTS AND DISCUSSION

Species Accounts

The species observed at the Koanaka Hills are listed alphabetically within families and genera. Specimens collected during the 2009 survey are noted under the heading 'Material.' 'Other records' refers to specimens collected in 2008 and 1965 (Bauer *et al.* 2009). Comments under the heading 'Location and Habitat' relate to the specific habitat where the specimens were collected, as well as the precise GPS coordinate data for that capture. Additional comments on the specimen(s) or collection is noted under heading 'Comments'.

Amphibia

Anura

Ptychadenidae

Ptychadena subpunctata (Bocage 1866)

Material. Thirteen specimens: TNHC 85033–45.

Location and Habitat. All 13 specimens were collected by digging into the dry pan west of Koanaka South at 20°09.20'S, 21°11.36'E. These specimens were buried less than 10 cm below the surface of the pan. The location was chosen when one individual was first noticed emerging from the soil after a slightly dewy morning.

Comments. These specimens represent the first published record of this species in QDS 2021 Aa.

Pyxicephalidae

Cacosternum boettgeri (Boulenger 1892)

Material. Nine specimens: TNHC 84956–64.

Location and Habitat. All nine specimens were collected by digging into the dry pan W of Koanaka South at 20°09.20'S, 21°11.36'E. These specimens were buried less than 10 cm below the surface of the dry pan at the same location where the *Ptychadena subpunctata* were collected.

Comments. These specimens represent the first published record of this species in QDS 2021 Aa.

Pyxicephalus adspersus (Tschudi 1838; Figure 3)

Material. One specimen: TNHC 85046.

Location and Habitat. This specimen was collected from the dry pan W of Koanaka South at 20°09.20'S, 21°11.36'E. It was buried approximately 20 cm below the surface in a state of torpor just below the same location that the other anurans were collected.

Comments. This specimen represents the first published record of this species in QDS 2021 Aa.

Reptilia

Squamata: "Lacertilia"

Agamidae

Agama aculeata Merrem 1820

Material. Five specimens: TNHC 84949–53.

Other records. TNHC 68737–40; TM 30778 (Bauer *et al.* 2009).

Location and Habitat. TNHC 84949–52 were collected in a dry pan at 20°09.20'S, 21°11.36'E. TNHC 84953 was collected on a dirt track between the Koanaka and Gcwihaba Hills.

Amphisbaenidae

Monopeltis anchietae (Bocage 1873)

Material. One specimen: KHH 124 (BNM registration number pending).

Location and Habitat. The remains of this specimen were collected from the stomach of a honey badger, (*Mellivora capensis*), which was trapped near Koanaka South. Due to the fossorial tendencies of both the prey and predator, it is presumed that this specimen was captured underground.

Comments. This specimen represents the first

published record of this species in QDS 2021 Aa.

Zygaspis quadrifrons (Peters 1862; Figure 4)

Material. Four specimens: TNHC 85060–3.

Location and Habitat. TNHC 85060–2 were collected from under logs in the bushes surrounding a dry pan at 20°09.03'S, 21°10.30'E. TNHC 85063 was collected in similar conditions at 20°09.20'S, 21°110.36'E.

Chamaeleonidae

Chamaeleo dilepis Leach 1819

Material. One specimen from 2009: TNHC 84965.

Other records. One specimen from 2008: KHH 008 (BNM registration number pending; Bauer *et al.* 2009).

Location and Habitat. The specimen was found brumating under thick ground cover in the shade of trees at 20°34.20'S, 21°11.41'E.

Gekkonidae

Chondrodactylus turneri (Gray 1864)

Material. No specimens were collected in the 2009 survey.

Other records. TNHC 68749–50 (Bauer *et al.* 2009).

Location and Habitat. This species was found on dolomitic rocks at the entrance to the cave system in Koanaka South (Bauer *et al.* 2009).

Lygodactylus capensis (Smith 1849)

Material. One specimen: TNHC 84989.

Location and Habitat. This specimen was collected from logs stacked near a fire pit at 20°09.30'S, 21°11.36'E.

Comments. This specimen represents the first published record of this species from QDS 2021 Aa.

Ptenopus garrulus garrulus (Smith 1849; Figure 5)

Material. One specimen: TNHC 85032.

Other records. This highly vocal species was heard calling sporadically during the 2008 survey, but was not collected (Bauer *et al.* 2009).

Location and Habitat. This specimen was collected in a burrow in tall grass, on loose sand substrate, 50 m west of Koanaka South at 20°09.30'S, 21°11.34'E.

Comments. Although previously published by Bauer *et al.* (2009) as present in the area based on sound records, this specimen represents the first vouchered record of this species in QDS 2021 Aa.

Lacertidae

Heliobolus lugubris (Smith 1838; Figure 6)

Material. Two specimens: TNHC 84967–8.

Other records. TM 30779; TM 30792 (Bauer *et al.* 2009).

Location and Habitat. These specimens were collected in sandveld darting under bushes at 20°09.20'S, 21°11.36'E.

Comments. Previously published as confirmed in the area based on collections by Wulf Haacke (Bauer *et al.* 2009). This specimen represents the first collection of the species near the Koanaka Hills since 1965.



FIGURE 3. *Pyxicephalus adspersus* from ephemeral pan near the Koanaka Hills.



FIGURE 4. *Zygaspis quadrifrons* found buried in shallow sand near Koanaka South.



FIGURE 5. *Ptenopus garrulus garrulus* from a shallow burrow in the Koanaka Hills.



FIGURE 6. *Heliobolus lugubris* from ephemeral pan near the Koanaka Hills.

Ichnotropis capensis (Smith 1838; Figure 7)

Material. 18 specimens: TNHC 84970–87.

Other records. TNHC 68743–7 (Bauer *et al.* 2009).

Location and Habitat. TNHC 84979 was collected on a dirt track near Koanaka South. TNHC 84971–8 were found in a dry pan at 20°09.20'S, 21°11.36'E. TNHC 84970 was found in a sandy area behind the main camp at 20°09.19'S, 21°11.24'E. TNHC 84981–7 were collected in a sandveld area darting under bushes at 20°09.52'S, 21°11.57'E. TNHC 84980 was caught in a pitfall trap placed in dense shrub northwest of Koanaka South at 20°09.31'S, 21°11.38'E.

Ichnotropis squamulosa Peters 1854

Material. No specimens were collected in the 2009 survey.

Other records. TNHC 68748 (Bauer *et al.* 2009).

Location and Habitat. In 2008 this taxon was found darting in and out from under bushes in the sandveld area surrounding the dry pan near Koanaka South (Bauer *et al.* 2009).

Pedioplanis namaquensis (Duméril and Bibron 1839)

Material. 34 specimens: TNHC 84994–5027

Other records. TM 3077; TNHC 68751–68 (Bauer *et al.* 2009).

Location and Habitat. All but one (TNHC 85015) *P. namaquensis* were active in and around the bases of shrubs in dry pans at 20°09.20'S, 21°11.36'E and 20°08.34'S, 21°11.41'E. TNHC 85015 was found in a sandy patch west of one of the pans at 20°09.03'S, 21°10.30'E.

Scincidae

Acontias kgalagadi kgalagadi Lamb, Biswas and Bauer 2010¹

Material. Two specimens: TNHC 85058–9.

Location and Habitat. THNC 85058 was found buried in the sand near the fire pit in the center of camp at 20°02.45'S, 21°11.76'E and TNHC 85059 was collected near the entrance of a rodent burrow at 20°08.30'S, 21°12.32'E.

Comments. These specimens represent the first published record of this species in QDS 2021 Aa.

Mochlus sundevalli (Smith 1849; Figure 8)

Material. Four specimens: TNHC 84990–93.

Location and Habitat. All specimens collected were found under logs. TNHC 84991 was found at 20°09.12'S, 21°11.59'E, TNHC 84993 was found south of Koanaka South at 20°09.52'S, 21°11.57'E, TNHC 84992 was found west of a pan at 20°09.30'S, 21°10.30'E, and TNHC 84990 was found near Gcwihaba at 20°09.12'S, 21°11.59'E.

Comments. These specimens represent the first published record of this species in QDS 2021 Aa.

Trachylepis varia (Peters 1867)

Material. Six specimens: TNHC 85047–52.

Other records. TM 30774–6; TM 30786–7; TNHC 68769–72 (Bauer *et al.* 2009).

Location and Habitat. All specimens collected in 2009 were found on Koanaka South running in and out of crevices between the dolomitic rocks.

Trachylepis wahlbergii (Peters 1869)

Material. Four specimens: TNHC 85054–7.

Other records. TM 30788; TNHC 68773 (Bauer *et al.* 2009).

Location and Habitat. All specimens collected were found under, or basking on, logs or rocks. TNHC 85055 was found at 20°09.03'S, 21°10.30'E, TNHC 85056–7 were found under logs in the dry pan at 20°09.20'S, 21°11.36'E, and TNHC 85054 was found near the road between the Gcwihaba and Koanaka Hills at 20°00.46'S, 21°39.34'E.

Squamata: Serpentes

Elapidae

Dendroaspis polylepis (Günther 1864)

Material. No specimens were collected in 2008 or 2009.

Other records. B. Williams (pers. com.) reported observing this species in a cave entrance on Koanaka South in 1996 (Bauer *et al.* 2009).

Psammophidae

Psammophis subtaeniatus Peters 1881

Material. Four specimens: TNHC 85028–31.

Location and Habitat. TNHC 85030–1 were caught in funnel traps placed near Koanaka South in the bushes at 20°09.31'S, 21°11.38'E, TNHC 85029 was found under a fallen burned tree (Figure 9) on Koanaka North at



FIGURE 7. *Ichnotropis capensis* found on sandy dirt track near Koanaka South.



FIGURE 8. *Mochlus sundevalli* found beneath a rotting log between Koanaka South and Koanaka North.

20°08.51'S, 21°12.25'E, and TNHC 85028 was collected from beneath a bush near Gcwihaba Hill at 20°01.27'S, 21°21.15'E.

Comments. These specimens represent the first published record of this species in QDS 2021 Aa.

Psammophis trinasalis Werner 1902

Material. No specimens were collected in 2009.

Other records. This species was listed as confirmed in the region by a sight record in 2008 (Bauer *et al.* 2009).

Location and Habitat. In 2008 this species was spotted moving down the slope of Koanaka South (Bauer *et al.* 2009).

Viperidae

Bitis arietans (Merrem 1820)

Material. No specimens were collected in 2009.

Other records. TNHC 68742 (Bauer *et al.* 2009).

Habitat. In 2008 one specimen was found basking in a dry pan near Koanaka South (Bauer *et al.* 2009).

Faunal Dynamics Analyses

Species Richness. A graphical representation of the Chao 2 rarefaction curves shows that they do not overlap with increasing samples (Figure 10). Rarefaction curves are most informative at the point of the highest sample. Therefore, a non-overlap of the upper bound 95% confidence interval in 2008 with the lower bound 95% confidence interval in 2009 suggests significantly higher potential species richness in 2009. **Species Composition.** A Jaccard dissimilarity index value of 0.3 indicates that in 2009 the faunal data were similar to those of 2008 that were collected before the Koanaka Hills were subjected to extensive bush fire.

Diversity Dynamics. The differences in the mean Shannon indices were not significant ($p=0.49$), indicating a similar diversity of herpetofauna between 2008 and 2009.

Ngamiland is one of the most remote regions in Botswana, and has been severely under-collected in general. One of only two full-length references on Botswanan herpetofauna (Auerbach 1987) references no amphibians and only four reptiles within QDS 2021 Aa. The paucity of collections may be attributed chiefly to the difficulty of access, although it was suggested by Bauer *et al.* (2009) that the herpetofauna of the Koanaka Hills is naturally less diverse than the herpetofauna of many other southern African localities. This is attributed to the region's relative lack of significant rocky habitat, which is favored by many southern Africa reptile taxa (Bauer 1999; Bauer *et al.* 2009). Furthermore, the arid nature of the Kalahari presents a challenge for any amphibians in the area due to their dependence on water for reproduction.

Our new collection in the Koanaka Hills supplements the previously published inventory by Bauer *et al.* (2009) who collected nine reptile species. Bauer *et al.* (2009) mentioned four additional species based on previous collections in 1965 (*Heliobolus lugubris*), sound records (*Ptenopus garrulus*), and sight records (*Dendroaspis polylepis*, and *Psammophis trinasalis*). We collected three additional amphibian and six additional reptile species in

2009, including two that were reported but not collected in 2008 (*Heliobolus lugubris* and *Ptenopus garrulus*). Of the nine reptiles collected in 2008, all but *Chondrodactylus turneri*, *Ichnotropis squamulosa*, and *Bitis arietans* were also collected in 2009.

In 2009, 109 specimens of 14 reptile species and three amphibian species were collected. This brings the confirmed herpetofauna near the Koanaka Hills to 22 species (three amphibians, 19 reptiles), including the two snakes identified by sight in 2008 (Bauer *et al.* 2009). For seven of those species, this report constitutes the first published record of occurrence in quarter degree square 2021 Aa. Despite the low diversity in the region, the probable species list for QDS 2021 Aa includes 15 frogs (up from an earlier estimate of six, Bauer *et al.* 2009) and 46 reptiles (Table 1).

Superficially, the analyses measuring the changes in the herpetofauna of the Koanaka Hills following a fire appear inconclusive. For example, comparisons of the species composition and diversity between years both suggest that the faunas were similar (using Shannon and Jaccard indices). Conversely, the species richness analysis suggests higher species richness in 2009 following the fire (using Chao 2 rarefaction curves). While collection technique and location were the same both years, differences in collection effort and weather conditions between years might account for the species richness results. For example, in 2008 fewer people focused on collecting the herpetofauna (1–2 on most days in 2008, versus 2–4 on most days in



FIGURE 9. Burnt tree beneath which one specimen *Psammophis subtaeniatus* was found.

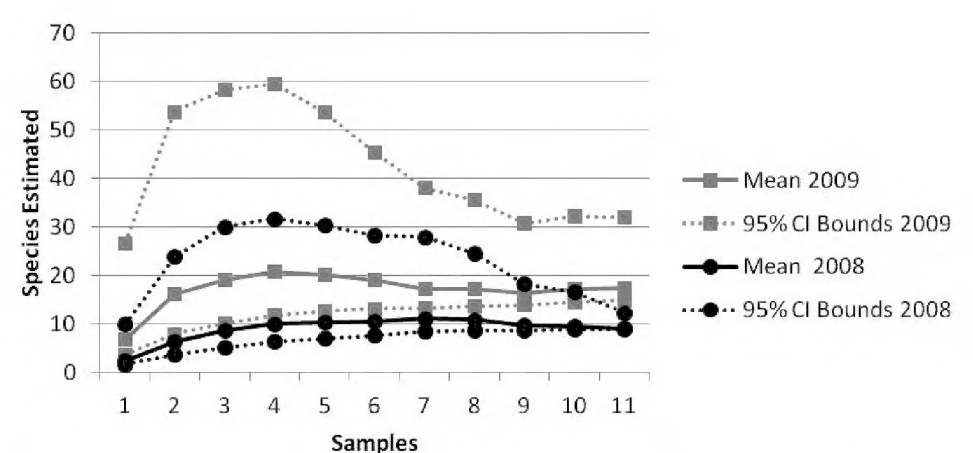


FIGURE 10. Chao 2 rarefaction curves for 2008 and 2009 predicting species richness with increasing samples. The 2008 upper bound 95% confidence interval curve does not overlap with the 2009 lower bound 95% confidence interval curve, which indicates a significant difference in the species richness of the herpetofauna in 2008 and the herpetofauna of 2009.

2009), and in 2009 there were six additional trapping days. Additionally, the weather was slightly warmer and wetter in 2009. During the 2008 collection daytime temperatures averaged 26°C, night time temperatures averaged 2°C, and there was no precipitation, whereas in 2009 daytime temperatures averaged 28°C, night time temperatures averaged 5°C, and light precipitation occurred one day during the collecting trip. Both higher temperatures and rainfall greatly increase the probability of encountering reptile and amphibian taxa in the dry, winter months. Since collection effort and weather conditions may account

for the significant result in the species richness analysis, the fire impact on the herpetofauna of the Koanaka Hills was likely minimal. While the frequency of fires in the Koanaka Hills is currently unknown, given the prevailing weather conditions in the region it would not be surprising if such events were frequent. It is possible that the fossorial lifestyle of some taxa and the use of rocky or subterranean retreat sites by many species among the Koanaka herpetofauna offers some protection from several local threats and environmental extremes, including fire.

TABLE 1. Checklist of observed and expected taxa at the Koanaka Hills. Confirmed species include those recorded from the Koanaka Hills region (a maximum of ~25 km distant from the Koanaka Hills): 1 = collected in 2009, 2 = collected in 2008, 3 = collected in 1965, 4 = unvouchered record. Unless noted by an asterisk (*), taxa in the list of expected species were plotted with ranges including the Koanaka region by Branch (1998) or Du Preez and Carruthers (2009). Additional literature records including the Koanaka Hills in shaded range maps are also indicated: Visser 1984 (a), Auerbach 1987 (b), Broadley 1990 (c), Carruthers and Du Preez 2011. (d), Channing 2001 (e), Clauss and Clauss 2002 (f), and Wüster and Broadley 2007 (g).

TAXON		CONFIRMED	EXPECTED
AMPHIBIA: ANURA			
Brevicipitidae	<i>Breviceps adspersus</i> Peters 1882		d, e, f
Bufonidae	<i>Amietophrynus gutturalis</i> (Power 1927)		d
	<i>Amietophrynus maculatus</i> (Hallowell 1854)		d
	<i>Amietophrynus poweri</i> (Hewitt 1935)		d
Hyperoliidae	<i>Kassina senegalensis</i> (Duméril and Bibron 1841)		d, f
Microhylidae	<i>Phrynomantis bifasciatus</i> (Smith 1847)		*, e
Pipidae	<i>Xenopus laevis</i> (Daudin 1802)		d
Ptychadenidae	<i>Ptychadena mascareniensis</i> (Duméril and Bibron 1841)		*, d
	<i>Ptychadena subpunctata</i> (Bocage 1866)	1	d
	<i>Ptychadena taenioscelis</i> Laurent 1954		d
Pyxicephalidae	<i>Cacosternum boettgeri</i> (Boulenger 1892)	1	d
	<i>Pyxicephalus adspersus</i> (Tschudi 1838)	1	d
	<i>Tomopterna cryptotis</i> (Boulenger 1907)		d, e, f
	<i>Tomopterna krugerensis</i> Passmore and Carruthers 1975		d
	<i>Tomopterna tandyi</i> Channing and Bogart 1996		d, e
REPTILIA: TESTUDINES			
Pelomedusidae	<i>Pelomedusa subrufa</i> (Bonnaterre 1789)		f
Testudinidae	<i>Stigmochelys pardalis</i> (Bell 1828)		f
	<i>Psammobates oculifer</i> Kuhl 1820		f
REPTILIA: SQUAMATA: “LACERTILIA”			
Agamidae	<i>Agama aculeata</i> Merrem 1820	1,2,3	f
Amphisbaenidae	<i>Dalophia pistillum</i> (Boettger 1895)		
	<i>Monopeltis anchietae</i> (Bocage 1873)	1	
	<i>Monopeltis mauricei</i> Parker 1935		g
	<i>Zygaspis quadrifrons</i> (Peters 1862)	1	
Chamaeleonidae	<i>Chamaeleo dilepis</i> Leach 1819	1,2	f
Gekkonidae	<i>Chondrodactylus turneri</i> (Gray 1864)	2	f
	<i>Lygodactylus capensis</i> (Smith 1849)	1	
	<i>Pachydactylus capensis</i> (Smith 1845)		
	<i>Pachydactylus punctatus</i> Peters 1854		a
	<i>Ptenopus garrulus garrulus</i> (Smith 1849)	1	f
Gerrhosauridae	<i>Gerrhosaurus multilineatus auritus</i> Boettger 1887		a, b
Lacertidae	<i>Heliobolus lugubris</i> (Smith 1838)	1,3	f
	<i>Ichnotropis capensis</i> (Smith 1838)	1,2	
	<i>Ichnotropis squamulosa</i> Peters 1854	1,2	
	<i>Pedioplanis namaquensis</i> (Duméril and Bibron 1839)	1,2	*
Scincidae	<i>Acontias kgalagadi kgalagadi</i> Lamb, Biswas and Bauer 2010	1	
	<i>Mochlus sundevalli</i> (Smith 1849)	1	f
	<i>Trachylepis varia</i> (Peters 1867)	1,2,3	
	<i>Trachylepis punctulata</i> (Bocage 1872)		a, b
	<i>Trachylepis wahlbergii</i> (Peters 1869)	1,2,3	f
	<i>Typhlacontias rohani</i> Angel 1923		
Varanidae	<i>Varanus albigularis</i> (Daudin 1802)		f



TABLE 1. CONTINUED.

TAXON		CONFIRMED	EXPECTED
REPTILIA: SQUAMATA: SERPENTES			
Atractaspidae	<i>Amblyodipsas ventrimaculata</i> Roux 1907		
	<i>Atractaspis bibronii</i> Smith 1849		f
	<i>Xenocalamus bicolor</i> Günther 1868		f
Colubridae	<i>Dasypeltis scabra</i> (Linnaeus 1758)		f
	<i>Telescopus semiannulatus</i> Smith 1849		f
Elapidae	<i>Aspidelaps scutatus scutatus</i> (Smith 1849)		c
	<i>Dendroaspis polylepis</i> (Günther 1864)	4	*, f
	<i>Elapsoidea sundevallii fitzsimonsi</i> Loveridge 1944		b, c
	<i>Naja anchietae</i> Bocage 1879		f
	<i>Naja mossambica</i> Peters 1854		b, g
Lamprophidae	<i>Boaedon capensis</i> (Duméril 1854)		f
Leptotyphlopidae	<i>Leptotyphlops scutifrons</i> (Peters 1854)		f
Psammophiidae	<i>Psammophis jallae</i> Peracca 1896		b
	<i>Psammophis mossambicus</i> Peters 1882		*, f
	<i>Psammophis subtaeniatus</i> Peters 1881	1	b, f
	<i>Psammophis trinasalis</i> Werner 1902	2	
	<i>Psammophylax tritaeniatus</i> (Günther, 1868)		
Pseudaspididae	<i>Pseudaspis cana</i> (Linnaeus 1758)		f
Typhlopidae	<i>Rhinotyphlops boylei</i> (FitzSimons, 1932)		
Viperidae	<i>Bitis arietans</i> (Merrem 1820)	2	f

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LITERATURE CITED

Alexander, G. and J. Marais. 2007. *A Guide to the Reptiles of Southern Africa*. Cape Town: Struik Publishers. 408 p.

Auerbach, R.D. 1984. Botswana's dangerous snakes. *Marung* 2(4): 3–5.

Auerbach, R.D. 1985. *The Reptiles of Gaborone*. Gaborone: Botswana Book Centre. 48 p.

Auerbach, R.D. 1986. First steps in Setswana herpetology. *Botswana Notes and Records* 18: 71–90.

Auerbach, R.D. 1987. *The Amphibians and Reptiles of Botswana*. Gaborone: Mokwepa Consultants. 295 p.

Bauer, A.M. 1999. Evolutionary scenarios in the *Pachydactylus*-group geckos of southern Africa: new hypotheses. *African Journal of Herpetology* 48(1&2): 53–62.

Bauer, A.M., A.M. Kennedy, P.J. Lewis, M.L. Thies, and M. Gabadirwe. 2009. The herpetofauna of Koanaka South and adjacent regions. *Herpetological Bulletin* 107: 16–26.

Botswana Department of Meteorological Services. 2009. Electronic Database accessible at http://www.weather.info.bw/resources/climate_fs.html. Captured on 16 January 2009.

Branch, W.R. 1998. *Field Guide to Snakes and Other Reptiles of Southern Africa*, 3rd edition. Cape Town: Struik Publishers. 399 p.

Broadley, D.G. 1990. *FitzSimons' Snakes of Southern Africa*, revised edition with addendum. Parklands, South Africa: Jonathan Ball and Ad. Donker Publishers. 387 p.

Broadley, D.G. 2001. Amphisbaenia: *Monopeltis sphenorhynchus* – Eastern wedge-snouted worm lizard. *African Herp News* 32: 23–24.

Broadley, D.G. and A.S. Baldwin. 2006. Taxonomy, natural history, and zoogeography of the southern African Shield Cobras, genus *Aspidelaps* (Serpentes: Elapidae). *Herpetological Natural History* 9(2): 163–176.

Butchart, D. 2000. *Wildlife of the Okavango*. Cape Town: Struik Publishers. 126 p.

Channing, A. 2001. *Amphibians of Central and Southern Africa*. Ithaca: Cornell University Press. 470 p.

Carruthers, V. and L. Du Preez. 2011. *Frogs and Frogging in Southern Africa*. Cape Town: Struik Publishers. 112 p.

Castiglia, R.M., M. Costi and F. Annesi. 2006. Molecular and karyological homogeneity in *Trachylepis striata* (Peters 1844) and *T. wahlbergii* (Peters 1869) Scincidae Reptilia. *Tropical Zoology* 19(1): 119–128.

Clauss, B. and R. Clauss. 2002. *Common Amphibians and Reptiles of Botswana*. Windhoek: Gamsberg Macmillan. 114 p.

Cooke, H.J. 1975. The paleoclimatic significance of caves and adjacent landforms in western Ngamiland, Botswana. *The Geographical Journal* 141(3): 430–444.

De Waal S.W.P. 1978. The Squamata (Reptilia) of the Orange Free State, South Africa. *Memoirs of the National Museum, Bloemfontein* 11: 5–61.

Du Preez, L. and V. Carruthers. 2009. *A Complete Guide to the Frogs of Southern Africa*. Cape Town: Struik Publishers. 488p.

Ferguson, A.W., M.M. McDonough, M.L. Thies, P.J. Lewis, and M. Gabadirwe. 2010. Mammals of the Koanaka (Nqumsta Hills) Region of Botswana: A Provisional Checklist. *Botswana Notes and Records* 42: 163–171.

FitzSimons V.F.M. 1935a. Notes on a collection of reptiles and Amphibians made in the southern Kalahari, Bushmanland and the Great and Little Namaqualand. *Annals of the Transvaal Museum* 15(4): 519–550.

FitzSimons V.F.M. 1935b. Scientific results of the Vernay-Lang Kalahari Expedition, March to September, 1930. Reptilia and Amphibia. *Annals of the Transvaal Museum* 16(2): 295–397, pls. X–XI.

FitzSimons, V.F.M. 1943. The lizards of South Africa. *Transvaal Museum Memoir No. 1*: 1–528, 24 pls., 1 map.

Haacke, W.D. 1966. A new gekko (Sauria, Geckonidae) from Bechuanaland. *Arnoldia (Rhodesia)* 2(25), 1–7.

Hughes, B. 1997. *Dasypeltis scabra* and *Lamprophis fuliginosus* - two pan-African snakes in the Horn of Africa: A tribute to Don Broadley. *African Journal of Herpetology* 46(2): 68–77.

Kelly, C.M.R., N.P. Barker, M.H. Villet, D.G. Broadley, and W.R. Branch. 2008. The snake family Psammophiidae (Reptilia: Serpentes): phylogenetics and species delimitation in the African sand snakes (*Psammophis* Boie, 1825) and allied genera. *Molecular Phylogenetics and Evolution* 47(3): 1045–1060.

Kelly, C.M.R., N.P. Barker, M.H. Villet and D.G. Broadley. 2009. Phylogeny, biogeography and classification of the snake superfamily Elapoidea: a rapid radiation in the late Eocene. *Cladistics* 24: 1–26.

Kennedy, A.M., B.-A. S. Bhullar, P.J. Lewis, and M.L. Thies. 2010. A preliminary analysis of a Plio-Pleistocene herpetofauna from Botswana: A conservative apomorphy-based identification; p. 49–51 *In*: M.B. Mostovski and M.N. Ovechkina, M.N. (ed.). *Proceedings of the 16th Conference of the Palaeontological Society of Southern Africa*. Pietermaritzburg: Interpak Books.

Lyman, R.L. 2008. *Quantitative Paleozoology*. Cambridge: Cambridge University Press. 348 p.

McLachlan, G.R. 1981. Taxonomy of *Agama hispida* (Sauria: Agamidae) in southern Africa. *Cimbebasia* series A 5: 219–227.

Pickford, M. 1990. Some fossiliferous Plio-Pleistocene cave systems of Ngamiland, Botswana. *Botswana Notes and Records* 22: 1–15.

Pickford, M. and P. Mein. 1988. The discovery of fossiliferous Plio-Pleistocene cave fillings in Ngamiland, Botswana. *Comptes Rendus de l'Académie des Sciences, Paris, Série II* 307: 1681–1686.

Uetz, P. 2012. The Reptile Database accessible at <http://www.reptile-database.org>.

- Ugland, K.I., J.S. Gray, and K.E. Ellingsen. 2003. The species accumulation curve and estimation species richness. *Journal of Animal Ecology* 72(5), 888–897.
- Van Regenmortel, G. 1995. Regionalization of Botswana rainfall during the 1980s using principal component analysis. *International Journal of Climatology* 15(3): 313–323.
- Visser, J. 1984. Akkedisie van Suider-Afrika. *Landbouweekblad* 1984 (41 part series).
- Wahlberg, J.A. 1994. *Johan August Wahlberg. Travel Journals (and Some Letters) South Africa and Namibia/Botswana, 1838–1856*. Cape Town: Van Riebeeck Society. 249 p.
- Wüster, W. and D.G. Broadley. 2007. Get an eyeful of this: a new species of giant spitting cobra from eastern and north-eastern Africa (Squamata: Serpentes: Elapidae: *Naja*). *Zootaxa* 1532: 51-68.

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